Status and prospects of passive sounding with radio-astronomical sources

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July 12 2012

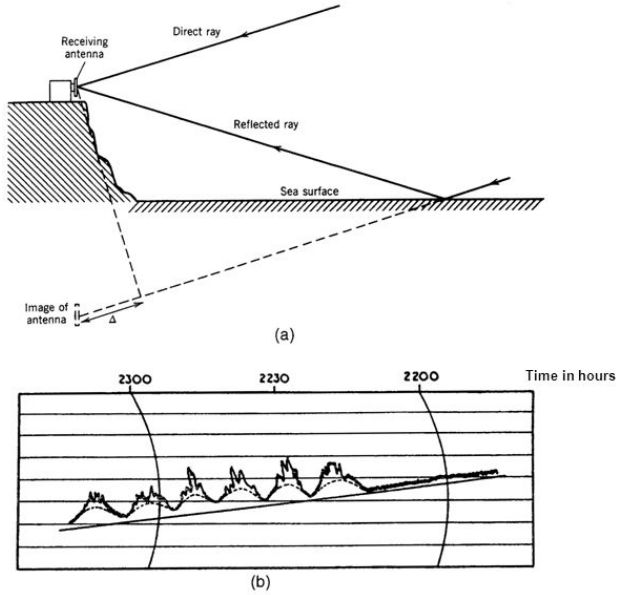
IGS 2019

Five Decades of Radio Glaciology

Foundations

Interferometry in radio astronomy

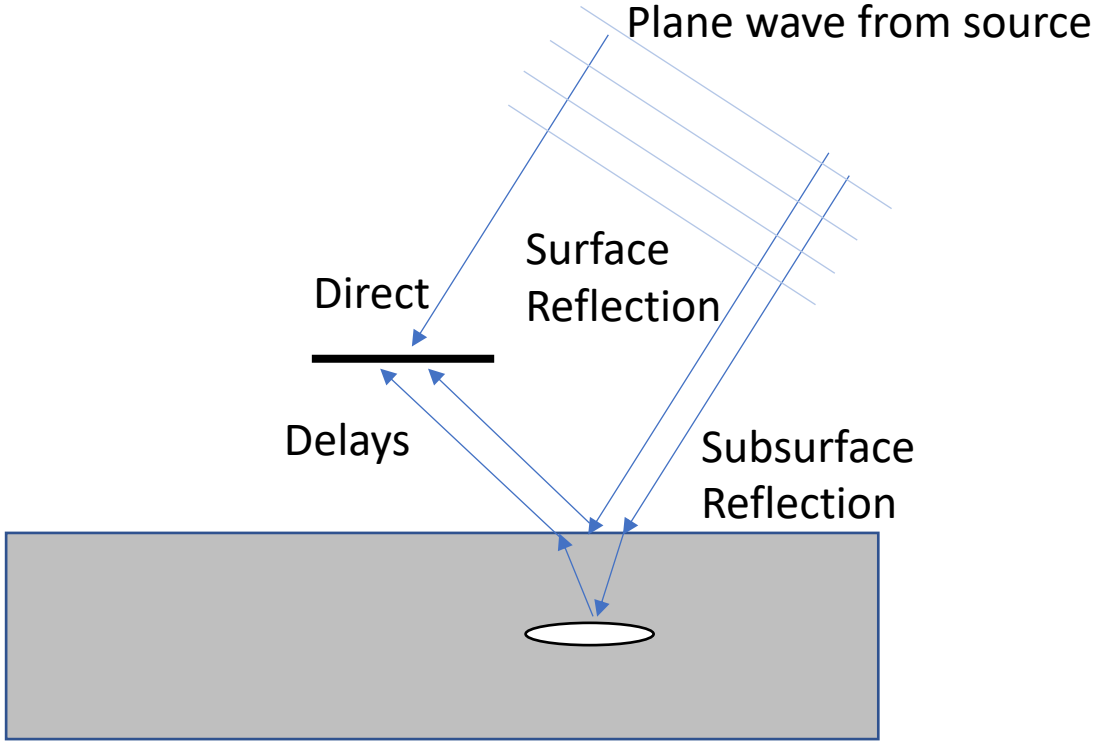
Sea Cliff Interferometer (Bolton and Stanley, 1948)



Response to Cygnus A at 100 MHz (Nature, 161, 313, 1948)

- Delay provided by antenna separation.
- Correlation peaks at location of source.
- Enables imaging with rotation synthesis or multiple antennas.

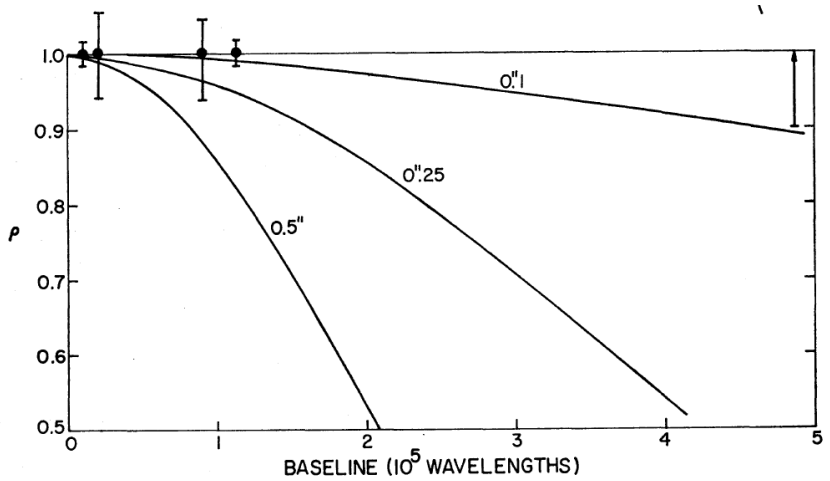
Passive Sounding



- Delay provided by different signal paths.
- Broadband correlation peaks at position of the reflector.
- Radargrams produced by synthesizing motion of spacecraft.

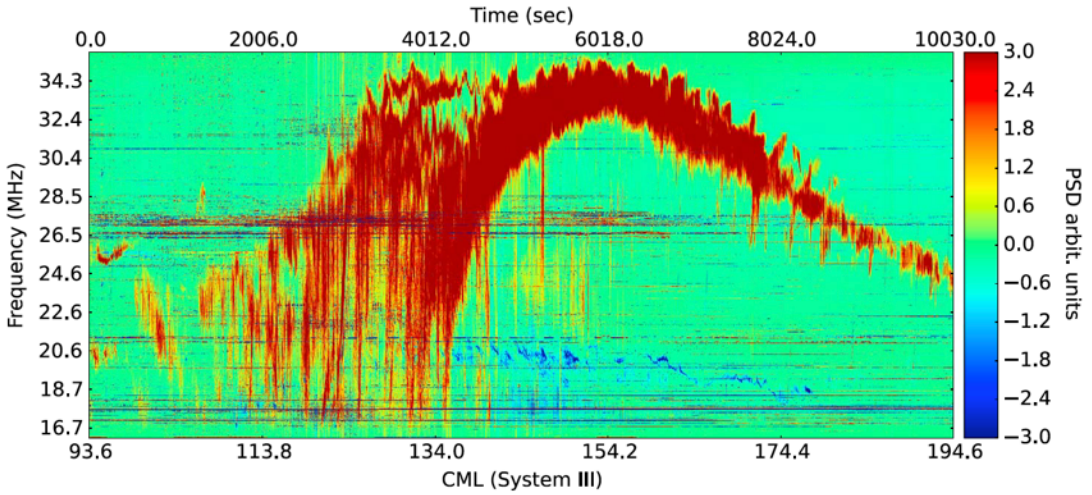
Properties of Jovian Bursts

Source of Jovian bursts is compact (< 1,000 km). Dulk, 1970, 34 MHz VLBI with stations in Clark Lake CA, Boulder CO, and Arrecibo

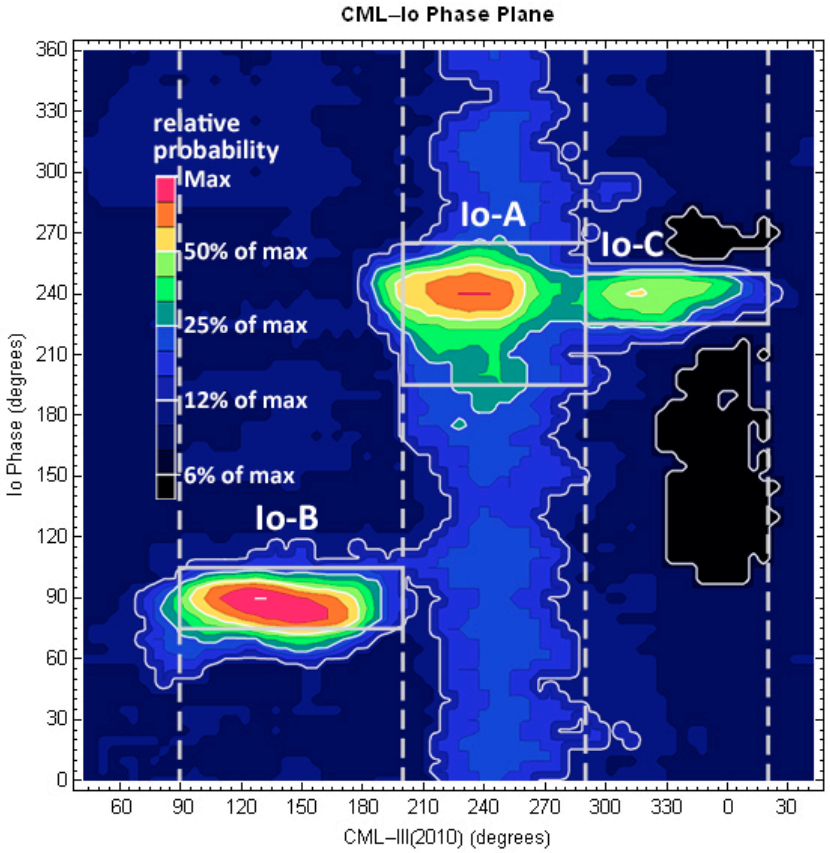


Source is broadband white noise. Typically ~3 MHz wide bands.

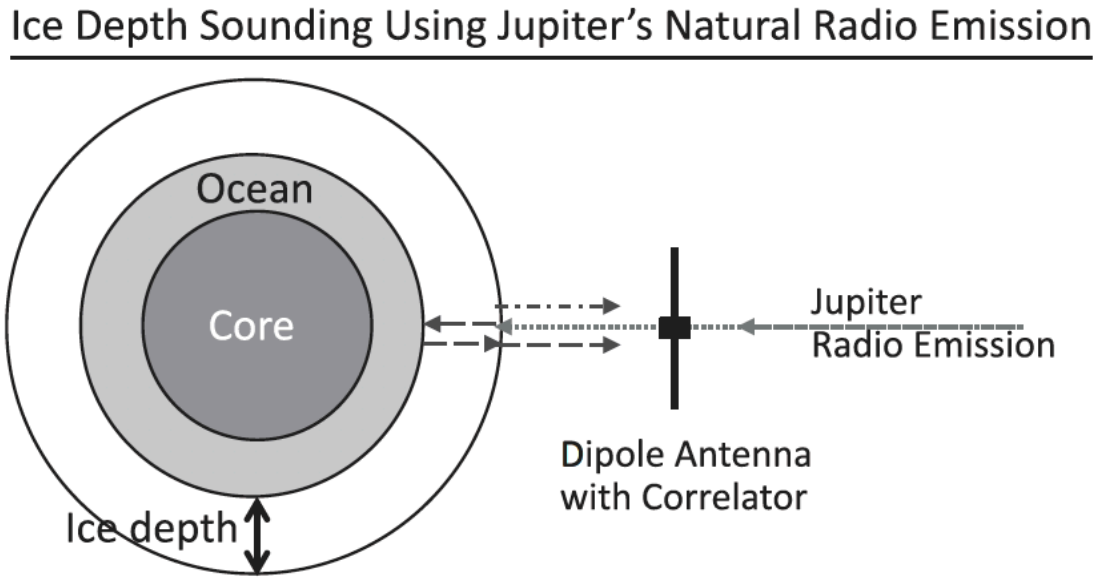
More on white noise characteristics later.

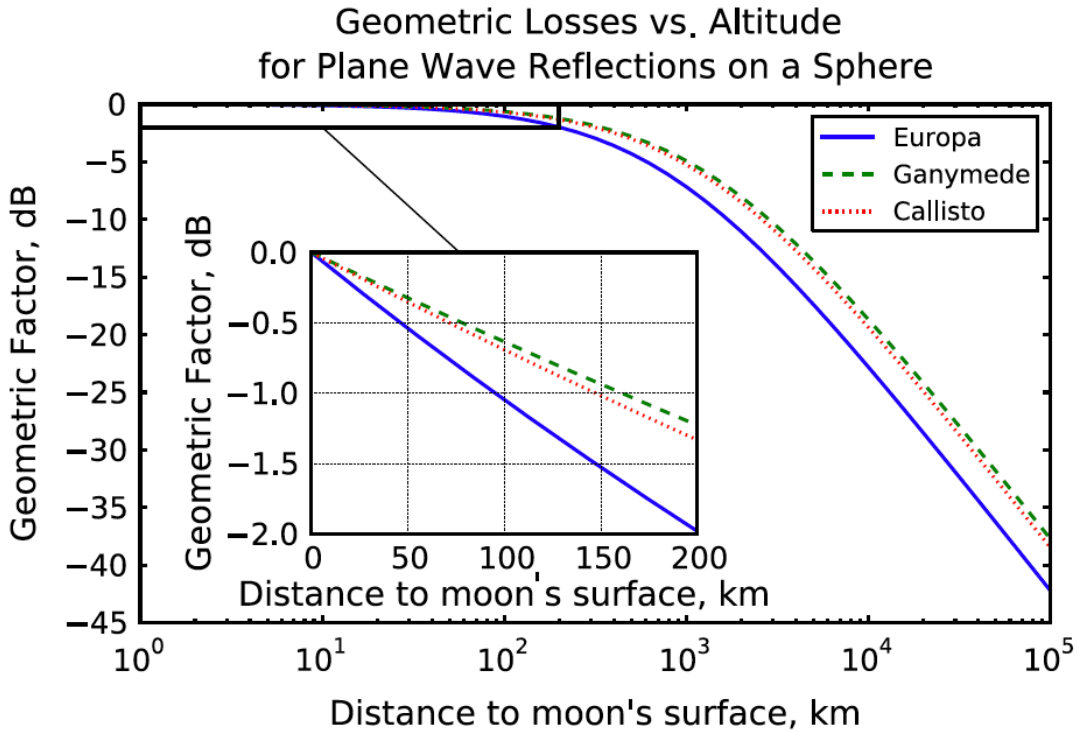


The strongest Jovian bursts are predictable based on Io orbital phase on Jovian longitudinal phase.



Sounding Jovian Icy Moons





- Bistatic sounding with a distant source does not result in inverse square losses for altitudes smaller than the radius of the body.
- This is where most of the gains in sensitivity of the technique arise.

Summary of Passive Sounding Concept

Originally proposed by Romero-Wolf et al., 2014

- Autocorrelation technique to extract timing and surface reflectivity information.
- Demonstrated autocorrelation works on rough surfaces.
- Identified Jupiter as a viable source (loud, compact, and broadband).

Initial assessment for RIME and REASON by Schroeder et al., 2015

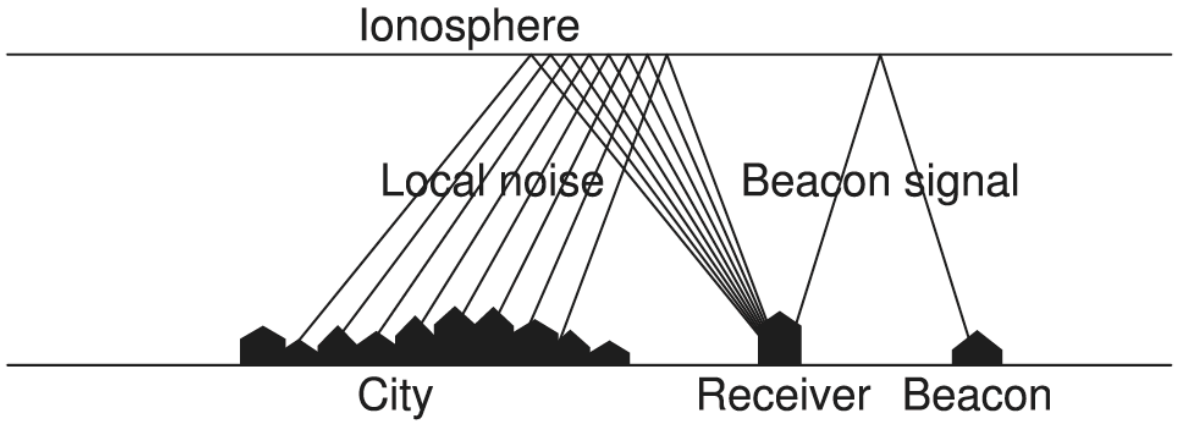
- Direct comparison of passive and active technique capabilities.
- Included effects of roughness and signal to clutter ratio (SCR).
- Passive sounding is compelling for sounding the sub-Jovian side, particularly for smoother portions of the surface.

Studies of Jovian radio bursts as a viable signal by Carrer et al. 2018

- Characterized non-whiteness of Jovian noise.
- Finds distortions in the correlation pulse shape.
- These are mitigated by flattening the spectrum at the cost of signal strength.
- More refined techniques currently under investigation.

Demonstrations

- Hartogh & Illyushin (2016) demonstrated correlation of urban noise could be used to detect the height of the ionospheric E layer.



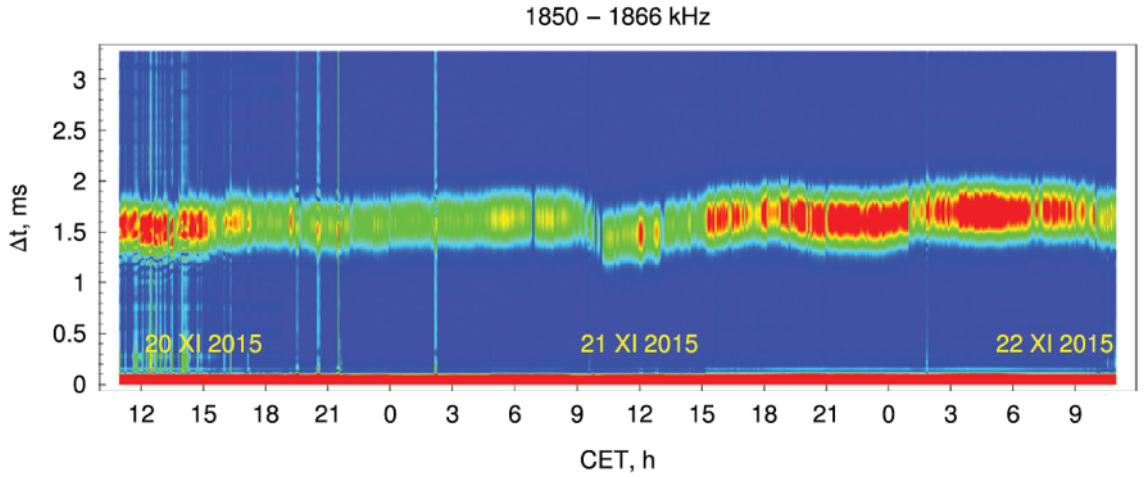


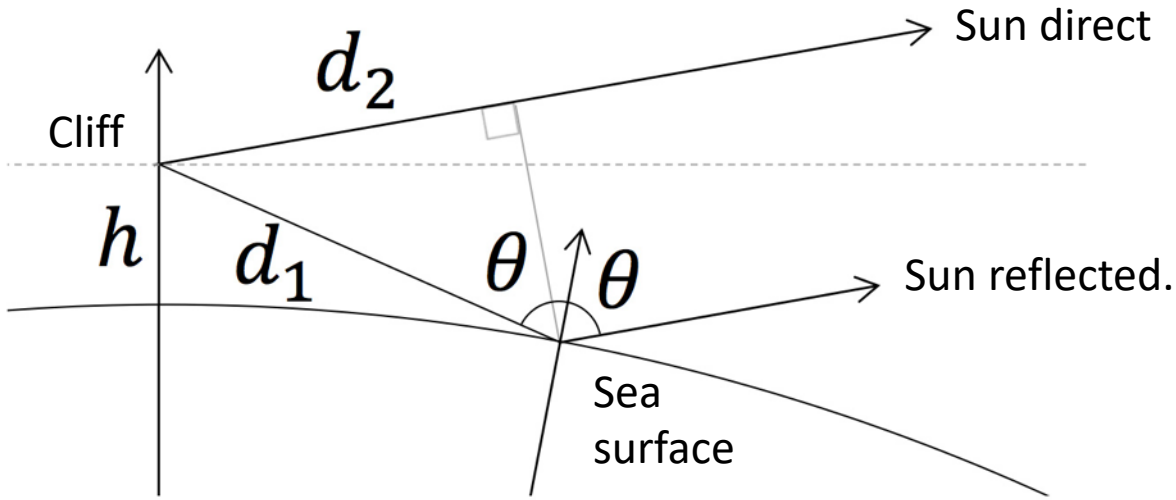
Fig. 13. Autocorrelation diagram of the ambient noise. Recording session November 20–22, 2015. The correlation peak time delay corresponds to the reflector pseudo-height about 100 km, typical for the ionospheric E layer.

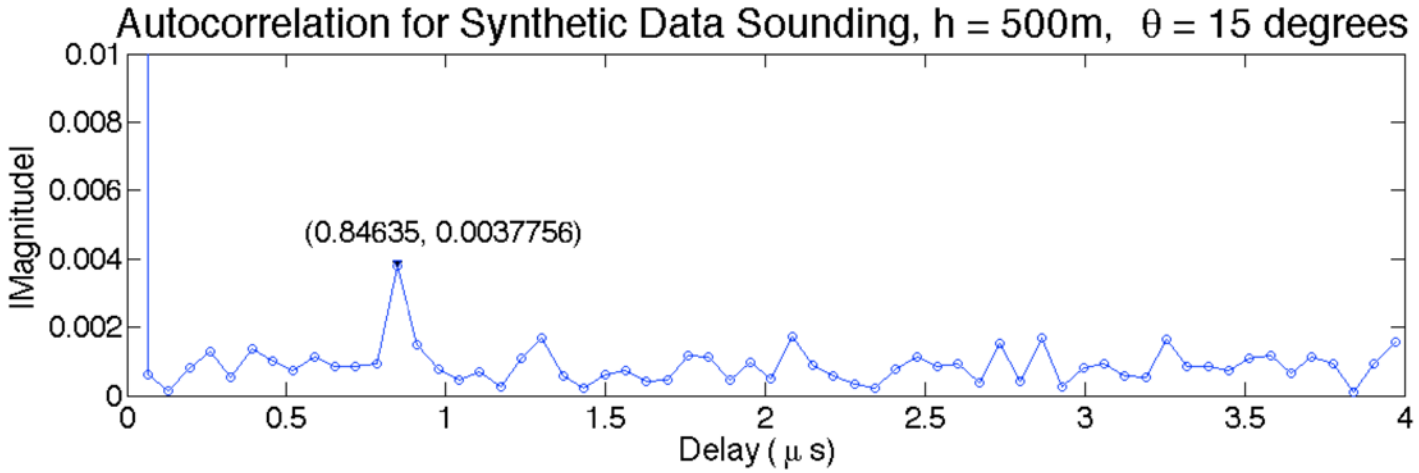
Demonstration with Radio Emission from the Sun

Measurement from Gorda cliff, California. Sun reflected off the sea surface.

Using a single antenna and receiver system, the correlation was identified.

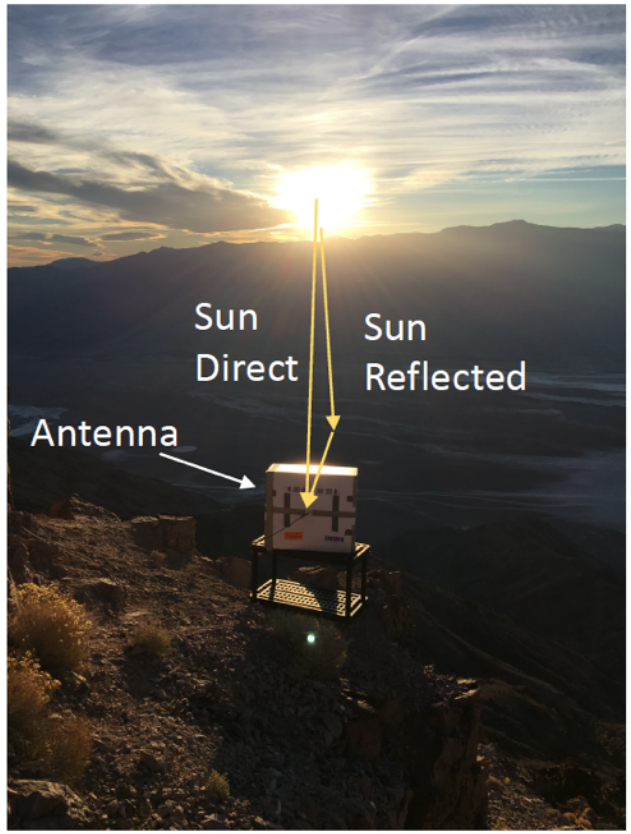
The peak delay and correlation amplitude were consistent with the model to within ~1 dB.

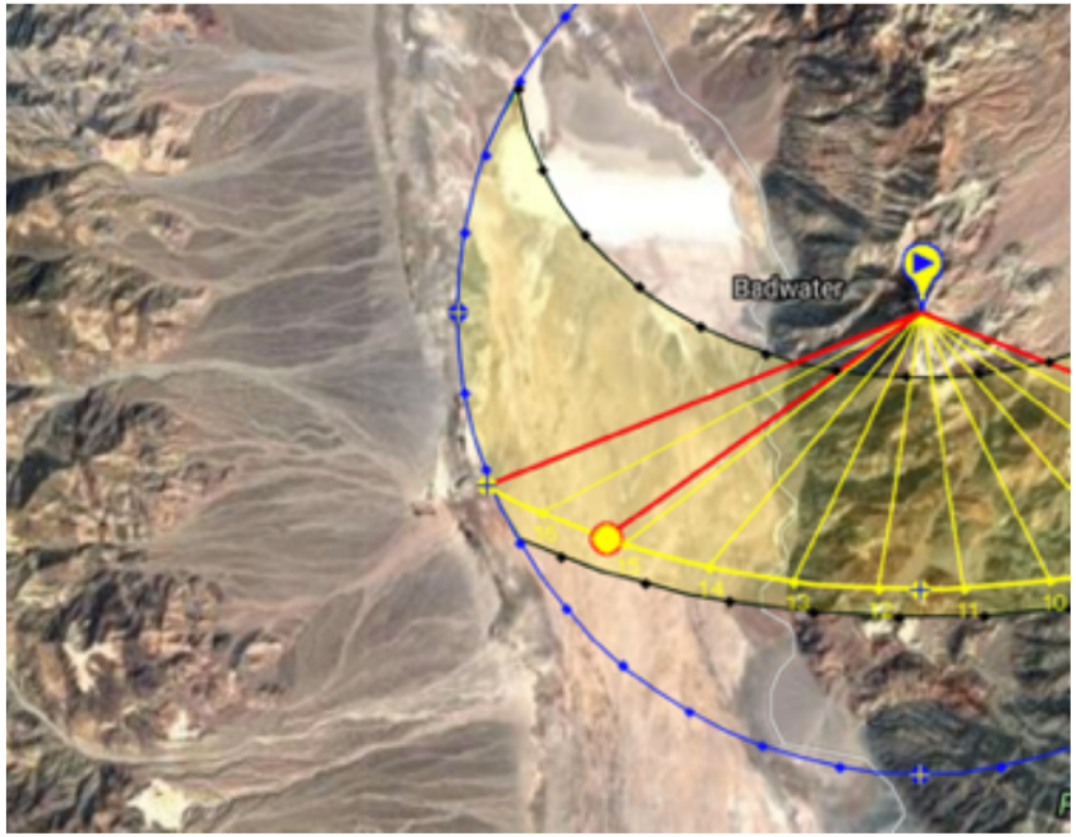




Peters et al., ITGRS, 2018

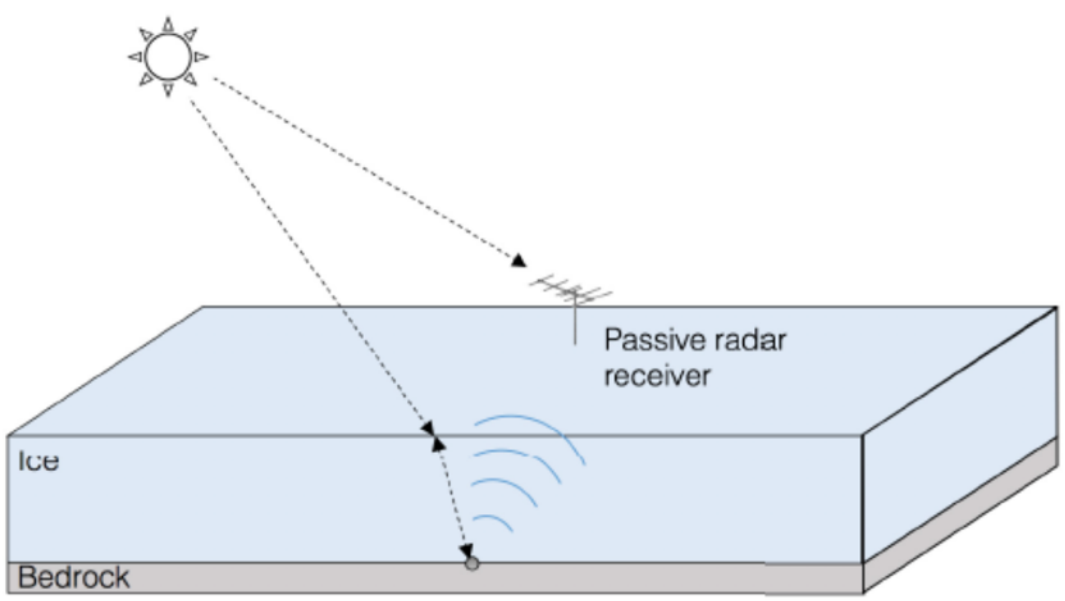
Demonstration with Radio Emission from the Sun





Dante's peak measurements taken to demonstrate tracking of the specular reflection of the Sun in the presence of surface roughness.

Demonstration with Radio Emission from the Sun



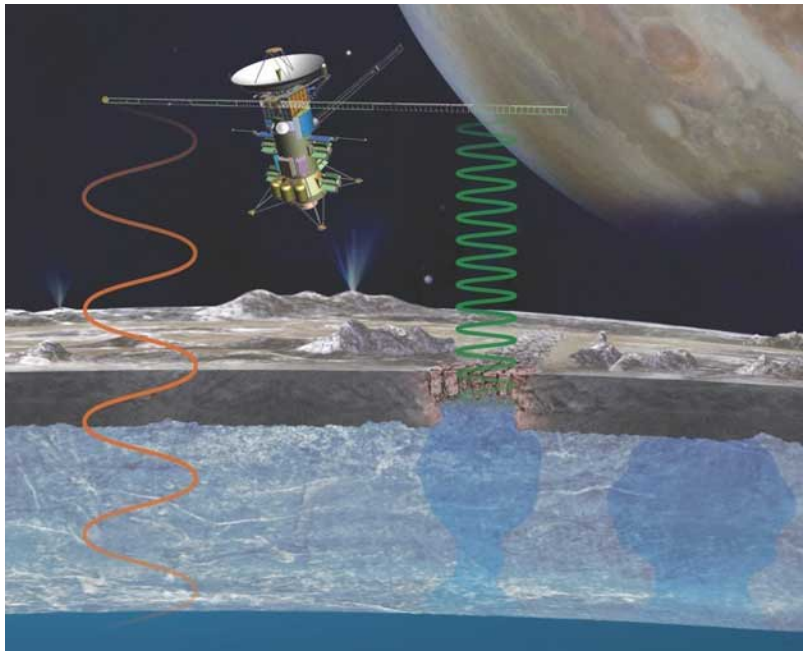
Successful sounding of the bedrock beneath ~1 km of Greenland ice sheet.

Concepts

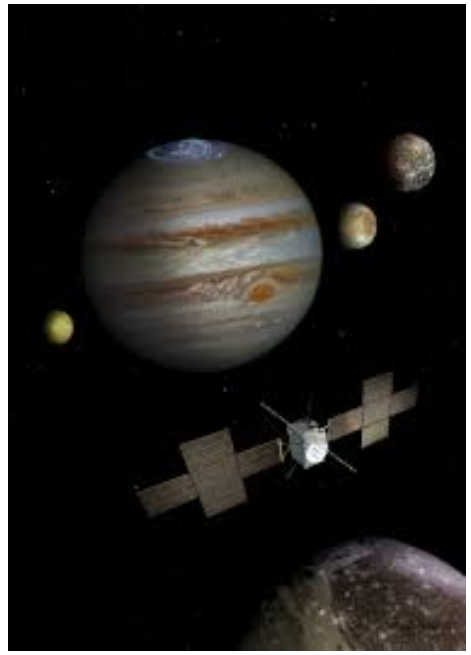
Complementary measurements with radar sounders.

- Leverage the receiver to use correlation technique in situ.
- Could be applied to any proposed sounder in view of the Sun or Jupiter, depending on the frequency of interest.

REASON sounding the sub-Jovian side of Europa in HF.

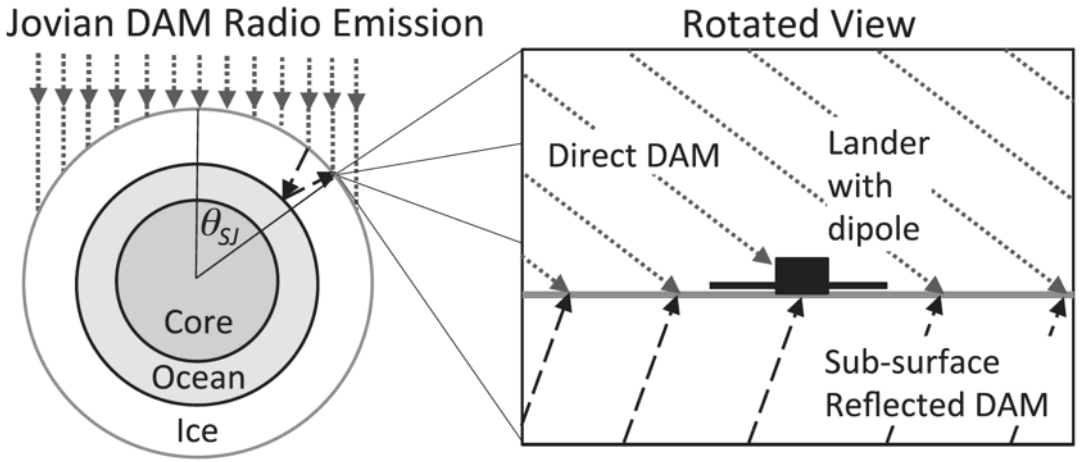


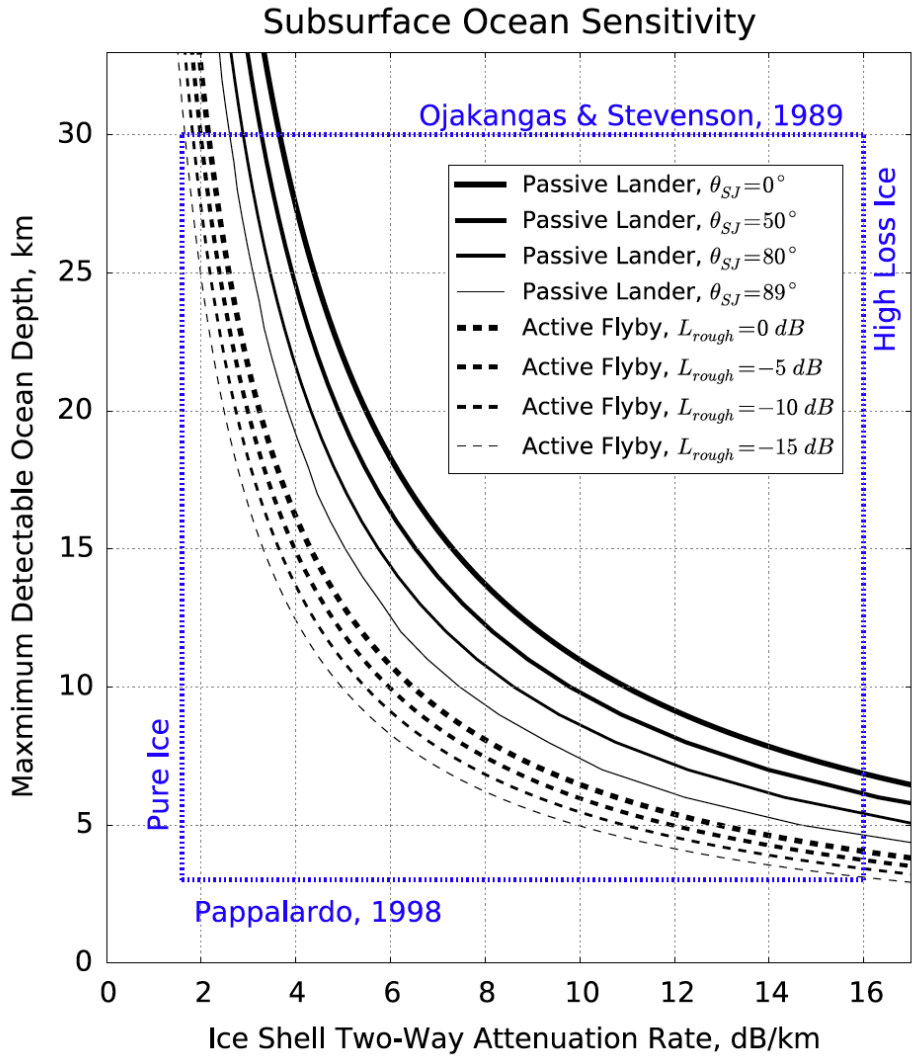
RIME sounding the sub-Jovian side of Ganymede in HF.



Lander

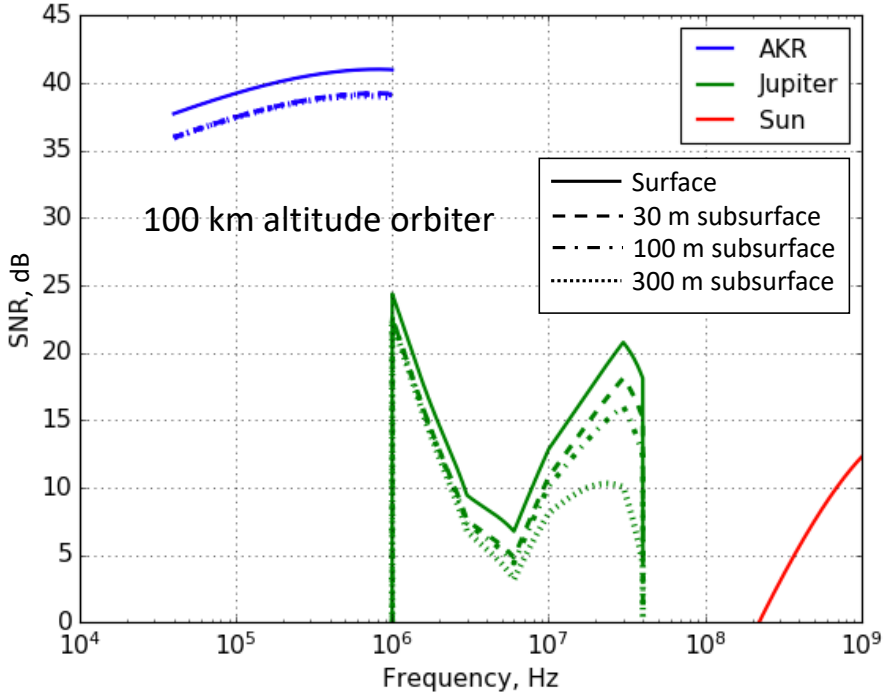
- Passive sounding on a lander does away with two major limitations: short integration times due to motion of spacecraft and surface roughness.
- Studied for Europa in Romero-Wolf et al. 2016.

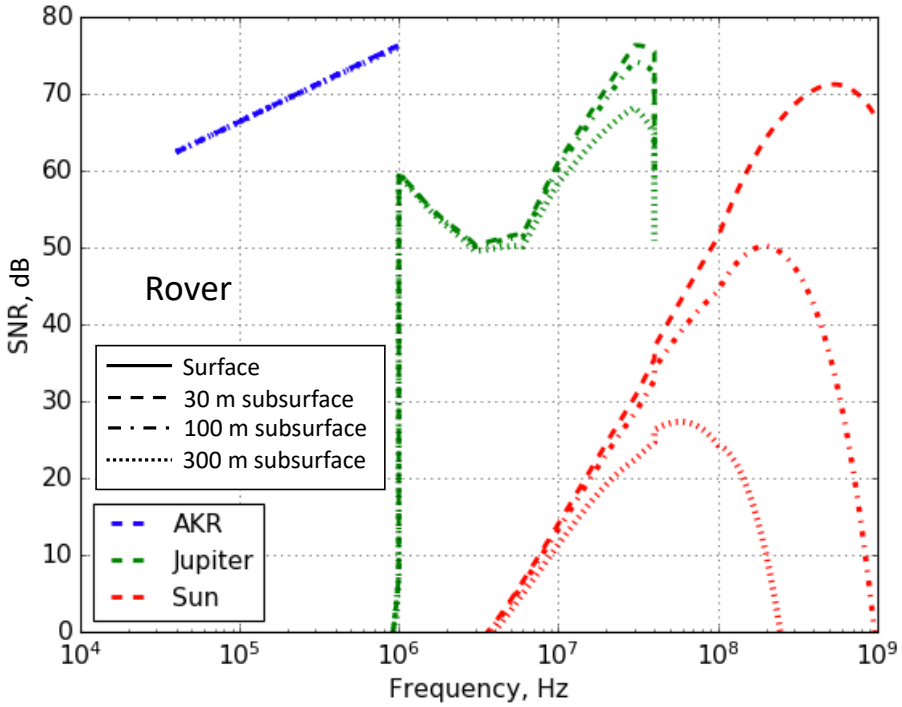




Lunar Lava Tubes

- A passive sounder orbiting the Moon would be capable of detecting lunar lava tubes.
- The JPL R&TD program has funded the development of a hardware prototype and field measurements to demonstrate feasibility with a low-resource implementation.
- Hardware is leveraging JPL's low frequency radio astronomy developments for SunRISE and other space-based low frequency observatory concepts.





Other Applications

Long term monitoring of Earth's ice sheets

- Network of low cost receivers on the surface of the ice can operate semi-continuously for extended period of time at low cost.

Ground-based radio astronomy

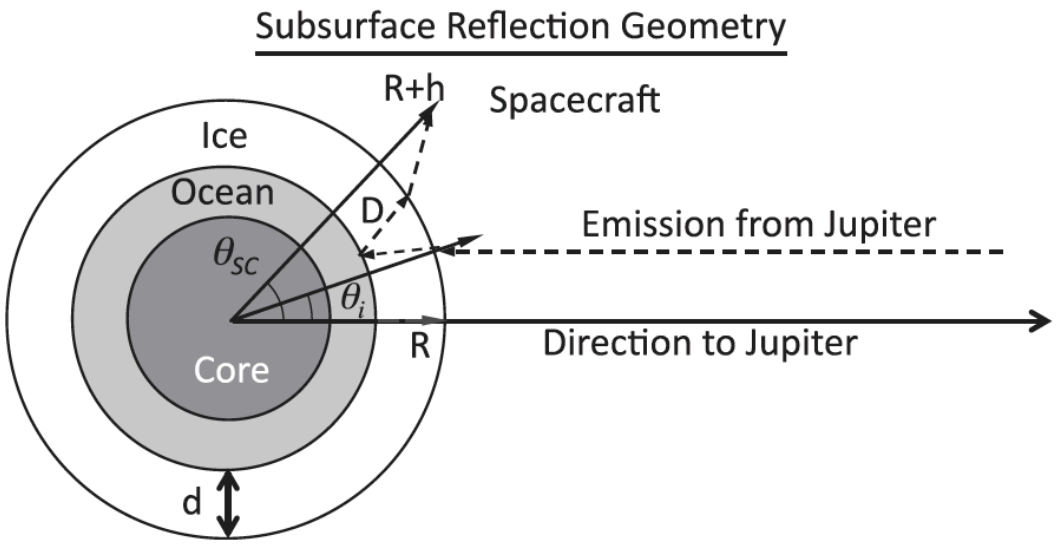
- The technique can be applied to powerful ground based radio astronomical telescope to search for autocorrelated structure.
- Polarimetric observation of reflected jovian bursts is a viable means of estimating the dielectric constant of the surfaces of Jovian icy moons.

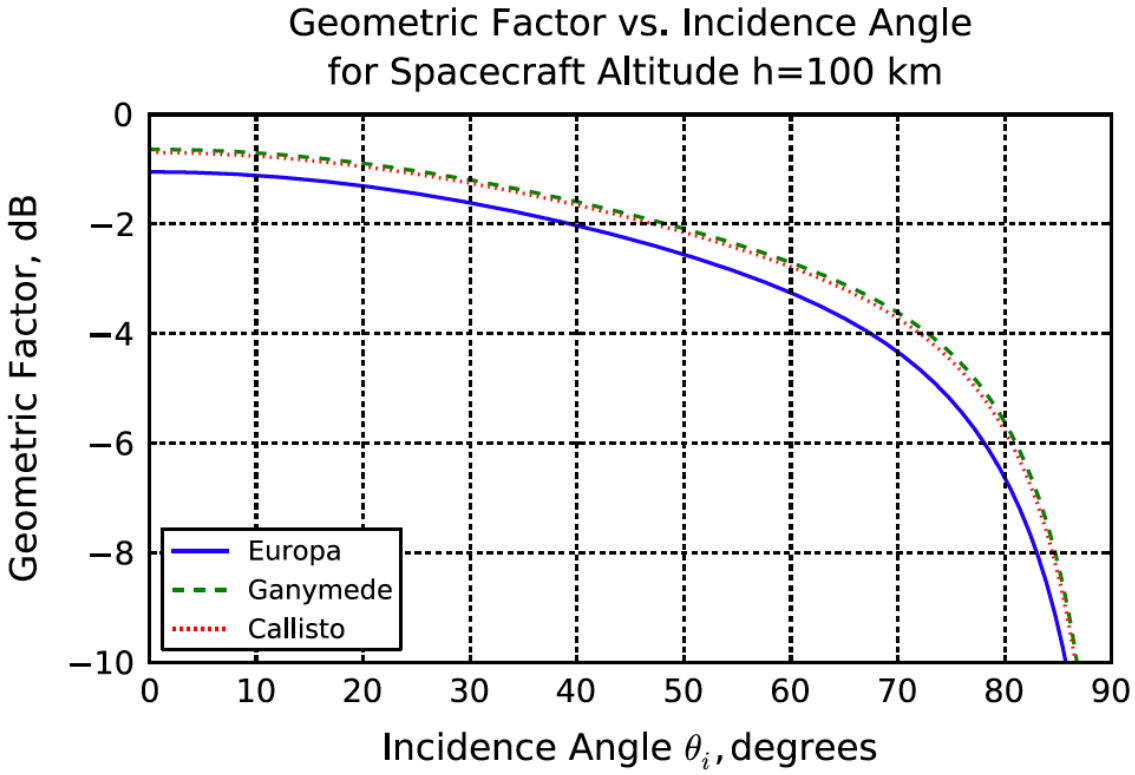
Outlook

- Passive sounding is a low-resource technique that can be used anywhere in the Solar System and in remote areas of Earth.
- Experimental demonstrations are proving it to be a viable technique.
- Prototypes of hardware designed to passively sound in real-time will inform the viability of low-cost space missions and applications for Earth.

Backup

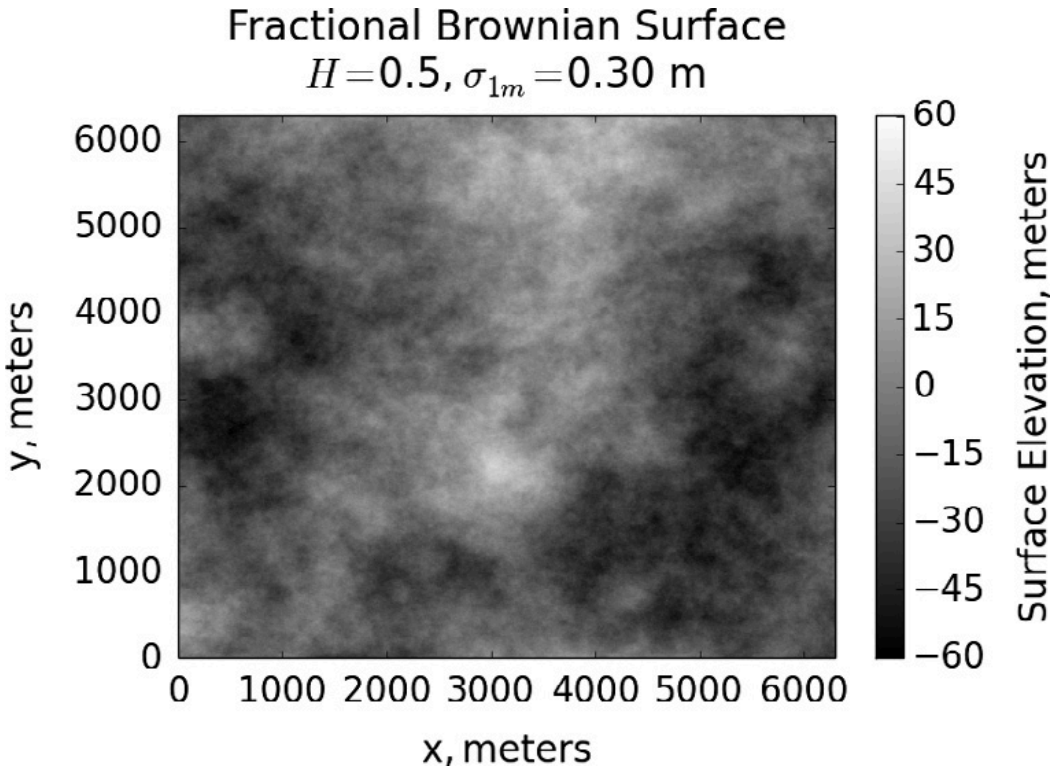
Sounding Jovian Icy Moons

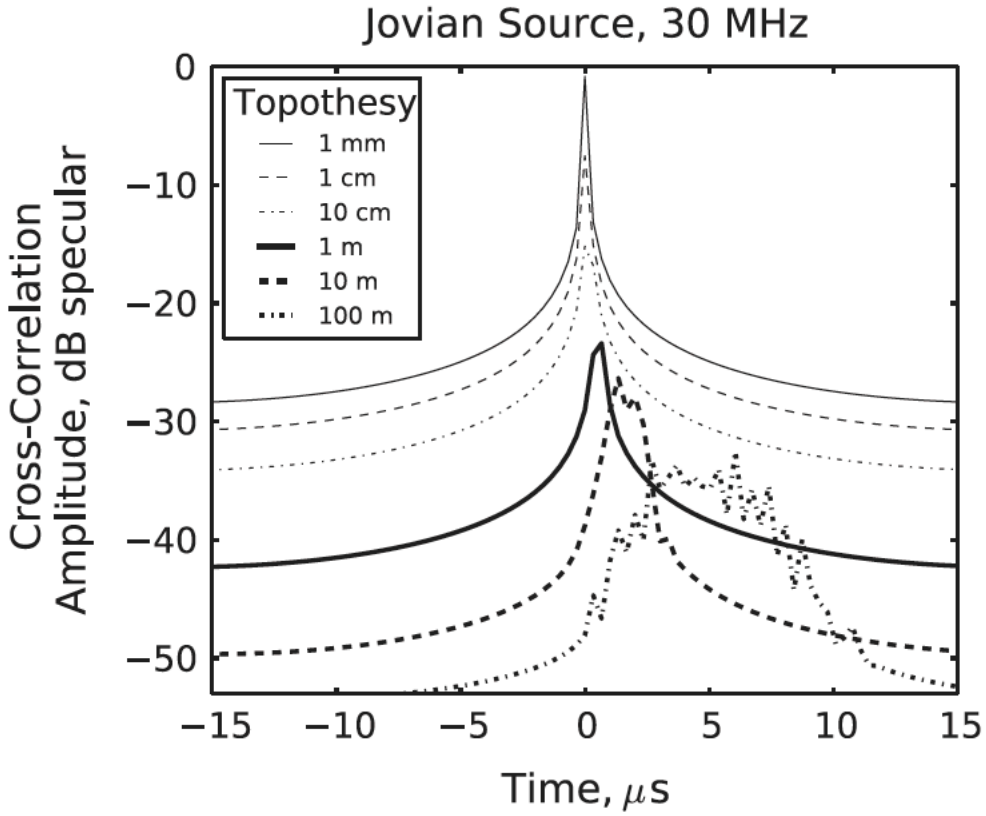




- Passive sounding is bistatic.
- The losses due to variations in incidence angle are within 3 dB for incidence angles $< 60°$.

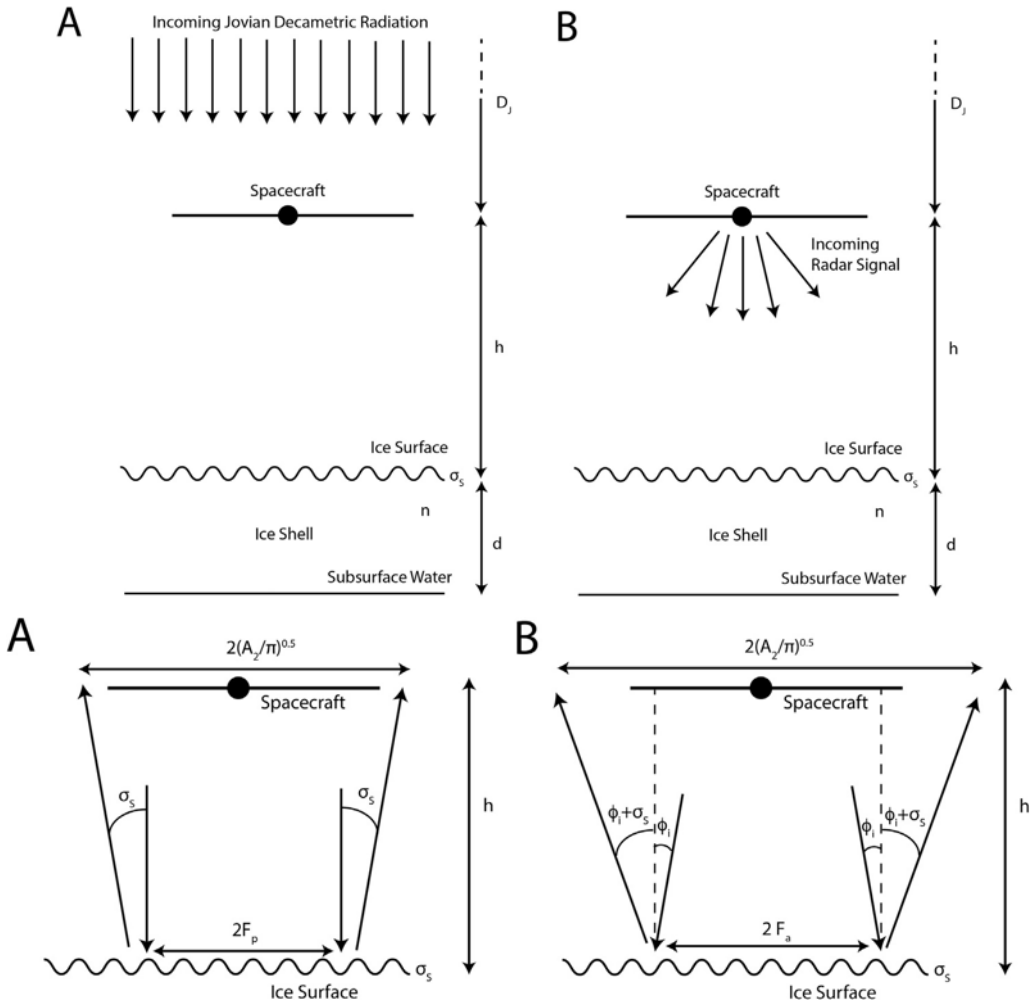
Correlation Function on Rough Surfaces





- Detection of correlated signal depends on the phase of the signal.
- Simulated a rough surface to show that despite phase noise being introduced, a correlated pulse still remains to some extent.

Roughness Effects



- Spreading losses due to roughness have a significant impact for passive sounding.